Automatic aerial surveillance of pipelines and the iNTeg-Risk (EU-funded GERG project)

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• The iNTeg-Risk project.
• Integration UAV – camera.
• Automatic georectification of images.
• Automatic thread identification.
• Emerging risk issues.
• Conclusions.
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What is iNTeg-Risk?

- An Integrated R&D Project supported by the European Commission (EC):
  - Within the 7th R & D Framework Programme of EC.
  - Aimed at providing integrated approaches for managing EMERGING RISK issues.
  - It will set up a framework for emerging risk management starting from 17 Industrial Applications, as an example.
  - 5 Subproject.
  - 88 partners.
  - Budget around 19 M Euros
Automated aerial surveillance Task

- Automated aerial surveillance of industrial facilities & pipelines ROW:
  - Aimed at using *light UAV* with visible / IR / thermal cameras & automated image processing for monitoring pipeline ROW and detect possible threads.
  - It is the largest industrial application in the project.
  - Budget ~1.43 M Euros.
  - Activities carried out in three tasks: 1.2.3, 3.1.2 & 4.2.2.
  - Partners:
    - **Pipeline operators:** GDF SUEZ (France) & Enagas (Spain).
    - **Technology providers:** Trimble, GDS, Mavionics / TU Braunschweig (Germany).
    - **R&D organisations:** INERIS, & Mines Paris Tech (France).
    - GERG.
**What is it a UAV?**

- **UAV: Unmanned Aerial Vehicle.**

- An UAV in the context of iNTeg-Risk is:
  - A small plane, < 12 kg.
  - With an autopilot flight control based on GPS and inertial sensors to follow the flight path.
  - Normally flying below 300 m (1000 ft).
  - In some way is similar to a Radio Control (RC) model.

- **UAV systems are becoming very popular for different application utilisation:**
  - Agricultural uses: crops and plague control.
  - Land use planning: control of new urban developments, identification of illegal construction, ....
  - Civil defence: monitoring of wildfire, flooding, inaccessible zones (i.e., Fukushima power plant), ....
  - Military application.
Different types of light UAVs
• To achieve an operational industrial system for automated aerial surveillance:
  
  - Reliable flight, no missed image, i.e., thread.
  - Right resolution & accurate georeferencing of images: needed for location of threads.
  - Adequate automated image processing, producing reliable alerts after automated processing, with limited human checking required.
  - Extensive operational validation needed under varied geographic & climatic conditions.

  - **To improve prevention of third party interference on pipelines by a better surveillance of ROW.**
  
  - To allow a good cost-benefit utilisation of this kind of pipelines surveillance.
• To study emerging risk issues related to automated aerial surveillance:
  – Technical, human & organisational issues.
  – Risk of a emerging technology, still not allowed by Authorities or/and with a lack of proper regulations.

• To reach a satisfactory level of acceptance for industrial operation of drones:
  – Acceptance by Civil Aviation Authorities.
  – Check regulatory and standardisation framework
  – Check acceptance by general public: tall infrastructure, local communities, etc.
Work under progress

- **Technological development:**
  - Integration of UAV and commercial camera.
  - Software for automatic georectification of still photographs taken by the UAV.
  - Automatic thread identification software.

- **Development of emerging risk issues:**
  - Identification of emerging risk for the different parts involved in the process.
  - The risk issues cover technological, human and organisational aspect.
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Adaptation of drone & camera system: flights in Spain, France

- Consumer camera operational in the two flights, improved operation in the second:
  - Importance of checking the camera settings before flight.
  - Importance of accounting for light conditions and time of day.

- Image data (*.jpg) from camera is linked by postprocessing to UAV position and orientation data. Image acquisition is triggered by GPS position and has a time stamp which allows the correlation with the position data in GPS file.

- Another camera to be adapted for next flights.
Flight in Spain & France: 20 & 40 km long

- The autopilot demonstrates that it can flight the pipeline ROW.
- Importance of setting camera controls according to the lighting conditions.
- Reliance on automatic exposure can be a problem.

- Comparison of the photo taken by the UAV with the original ortophoto (taken by conventional plane), it is clear that the quality and size of the new photos should facilitate to detect any activity near the pipeline.
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Fully automated UAV acquires imagery using a digital camera. Autopilot is able to keep the aircraft on the flight path with a tolerance of +/- 3m.

**Autopilot (positioning data):**
- Acquisition of flight path position data (GPS).
- Calculation of consecutive position information in two directions for position data improvement and gap filling (GPS 1Hz, autopilot 100 Hz).
- Orientation of aircraft (MEMS-IMU, Pitot-measurement, Altitude measurement).
Image Adjustment: Processing chain

Continuous data collection: Position + Orientation onboard UAV

Reference Check immediately after landing for completeness of image & position data and compliance with flight planning

Correction of lens induced image geometry errors

Calculation of **relative position** of overlapping images by means of scale invariant feature points

*Image chains without position data can cumulate errors (more than 100m)*

GPS-Signal and MEMS-IMU data provide **absolute image position**

*System errors larger than image objects (10-20m) if time stamp error is not corrected (3-6m)*

Intelligent combination of information sources results in an accuracy of 2-3m (crosschecking plausibilities), without any Ground Control Points (GCP)

Image data resampling (repositioning of pixels)

Image enhancement (density, brightness and lens induced lighting effects)

Final image product as classification input
Continuous flight track of approximately 2*20 km in France near Nancy

More lessons learnt

Loops to ensure adequate rolling angle can be a severe range limitation

Targets are key

Challenge of finding best combination of altitude & velocity to ensure good coverage and decrease blur

More lessons learnt
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### Threat detection / identification workflow

- **Analysis concentrated:**
  - **Phase A)** thread detection based on multiple changes of 2 successive images taken at T1 & T2 (2009-2010).
  - **Phase B)** thread detection based on individual images (2011 onwards)

- **To A) Change detection analysis workflow:**
  - For each time, to define change detection classification parameter (Brightness, Ratio of red, Edges of objects).
  - Classification of individual parameter changes.
  - Identification & Qualification of accumulated changes:
    - Quantification by a different weight to each change.
Create parameter changes classification

- Basis for change detection are filtered images:
  
  **Brightness:**
  red+blue+green

  **Ratio of red:**
  \[
  \frac{\text{red+blue+green}}{\text{red}}
  \]

  **Edges of red**
  (Canny's algorithm)

- => ratios and edges give back more stable values over different scenes
Classify object-based changes for parameter

- **Result**

  - **Brightness Change**
  - **Ratio Red Change**
  - **Edges Change**
Identify and quantify changes

- The sub-levels are basis to classify the accumulated change class:
  - Change in a single parameter
  - Change in two parameters
  - Change in three parameters

- Quantification based on:
  - Existence of changes.
  - Large differences in changes.
  - Features on base map.
The change detection approach requires a sufficiently co-registered set of image pairs taken at different times with light-weight UAVs.

The object recognition approach will allow automated image analysis to work on available data, allowing realistic risk analysis as well.

**Phase B**) Object recognition as Thread detection method
- An alternative, if no matching images are available
- Higher degree of flexibility
Threat Detection & Classification Workflow

Basemap

Automatic Threat Detection

Georeferenced UAV Imagery

Operator driven Threat Verification & Classification

Threat Database

Threat Management & Reporting

Pipeline Management System
1st: Prototype with manual check: is it a threat? YES / NO
2nd: What type of threat is it? Digger, construction yard, etc.
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Emerging Risk Issues

- To develop a methodology to manage emerging risk related to new technologies is the main objective of iNTeg-Risk project.

- This will be achieved by building a new management paradigm for emerging risks as a set of principles supported by a common language, agreed tools & methods, and Key Performance Indicators, KPIs, all integrated into a single framework.

- For developing these framework 17 examples of industrial application of new technologies are used, each one should identified the Emerging Risk Issues, ERI, affecting it.

- In the automated aerial surveillance task has been identified ERIs:
  - Related to the technological development.
  - Related to technology acceptance issues.
  - Related to the system performance.

- For each ERI is needed to develop appropriated KPIs.
ERIs related to technological development

- UAV & image collection reliability:
  - UAV Failure or Loss of Control.
  - Quality of images taken.
  - Geographical information, GPS & UAV flight parameter, needed for georeferencing and mosaicing.

- Automated image processing capabilities:
  - Accuracy of mosaicing process.
  - Automated thread identification process:
    - Image processing failure: no thread reported.
    - Missing threads: affects safety.
    - Reporting of non-existing threads: affects economy of system.
    - Threads reported with missing or wrong geo-location: affects safety.
    - Exceeding maximum reporting time: threads reported too late.
    - Communication failure: thread detected but nor submitted to operator.
ERIs related to technological acceptance

• Civil Aviation Authorities acceptance
  – Lack of clear regulation in Europe nowadays:
    • Problems to get authorisation to perform the surveillance work.
    • To perform the work without an appropriate authorisation.
  – Lack of failure frequencies for this type of plane.
    • Most of available FF related to military application.
  – Risk of collision against a manned plane:
    • Normally, size and weight of UAV should not be a hazard.

• General public & concerned stakeholders acceptance:
  – Concern about noise.
  – Management of images taken in private properties.
  – Fear of collision against private properties:
    • Normally, size and weight of UAV should not be a hazard.
ERIs related to system performance

• The main issue is how to estimate the contribution of surveillance with a UAV system to the reduction in current risk of pipelines.

• It is necessary to evaluate the "benefit / risk / cost" balance.

• In the context of risk management the evaluation must cover several criteria in an integrated way:
  – Performance and quality, safety, economy, workload or ecology in order to assess the improvements and anticipate unexpected changes related to the new technology.

• Based on a review of pipeline risk management aimed at external interference, two aspects have been identified:
  – A functional specification of the performance expected from this new technology for aerial surveillance
  – A modelling framework and method to be implemented to allow the evaluation of expected and unexpected consequences of change in order to support decisions.
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Conclusions

• Light UAV seems suited for aerial surveillance:
  - Can operate autonomously over 20 – 40 km.
  - Can collect images, but improvement is needed in synchronization of image time and GPS time.
  - A lot supplier of this technology in the near future.

• Automated image processing:
  - Threat detection very promising at this stage.
  - Threat identification confirmation is currently manual – needs significant improvement, and more flights to learn.
  - To decide between the Change Detection or Object Recognition strategies.

• System acceptance:
  - Civil Aviation Authorities:
    • Experimental use accepted.
    • Clear Regulation needed in the future.
  - General public & concerned stakeholders: survey is under execution.

• System performance:
  - Evaluation of contribution to improve prevention of external interference on pipelines is planned.
Thank you for your attention